TIME RESOLVED MEASUREMENTS OF PULSE INTENSITY, FILTER MOVEMENT AND REGENERATION DURING CLEANING OF BAGHOUSE FILTERS

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ABSTRACT

The “cleaning intensity” of a filter bag during pressure-pulse regeneration is a determining factor for both the stability of the filtration cycle and the emission level. On the other hand, the relationship between the shape of a pressure pulse signal, the resulting movement of the filter media (i.e. position, velocity, acceleration), and the removal of dust from the surface and/or interstices of the filter media is still not fully understood.

An experiment has been designed around a coupon filter testing unit (VDI Type 1), to measure all three components of this puzzle with a high time resolution. Filter movement is measured by triangulation; dust cake removal by high-speed imaging; and the internal dust currently via the residual pressure drop. Measurements on one type of filter media and one type of dust have shown how different phases of the pressure signal correlate with different stages of media motion. In case of sufficient cleaning intensity, it was found that cake detachment occurs for a constant product of deceleration and dust mass, i.e. at a fixed threshold force. In case of low pulse intensities, when the required acceleration is not reached, cake detachment occurs much later, due to back-flushing.

KEYWORDS

Pulse jet cleaning, surface filtration, cleaning efficiency, residual pressure drop.

1. Introduction

Dust emissions from baghouse filters are well known to occur primarily during the brief time intervals following each cleaning pulse (Klingel and Löffler, 1983; Sievert, 1987). Moreover, these emissions are due almost exclusively to direct penetration of very fine particles in the size range of the MPPS, a size range which is also very relevant for PM2.5 fine dust (Kasper et al. 2007; Binning et al., 2009; Kurtz et al., 2016a), provided of course the filter unit is free of leaks (Kurtz et al., 2016b). We also know that the emission level, best expressed in terms of dust mass per cleaning pulse (Kasper et al., 2007), generally increases with pulse intensity as defined primarily by the tank pressure. What is not well understood however, is the exact relationship between the "intensity" of the cleaning pulse, the resulting movement of the filter (acceleration, stretching, etc.), and the regeneration effect.

For a given filter medium, the cleaning intensity is related to the shape and magnitude of pressure pulse arriving at the filter surface. It depends in a complex way on various parameters such as the geometry of the filter unit as well as the permeability and flexibility of the media (Binning et al., 2007). The term "regeneration" encompasses different aspects of dust removal from the filter surface, including the degree of cake removal (determined by e.g. gravimetric or optical techniques – Dittler et al., 1998), as well as the permeability of the filter (often expressed in terms of residual pressure drop). Optimizing the filter regeneration requires a better understanding of all the processes involved and the resulting changes in filter performance.

This paper describes experiments designed to study the behavior of a cleanable filter during jet pulse regeneration in order to understand the relationship between jet-pulse intensity, filter (media) movement, and regeneration. It first describes the experimental set-up and approach. The results are presented in terms of (a) the relationship between filter (media) movement and pressure pulse characteristics; (b) the relationship between the movement of the filter media and dust cake removal. Finally we discuss future strategy.

2. Experimental set-up and procedures

Modified lab scale test rig for flat media samples. Experiments are based on a modified VDI Type-1 filter testing unit (Gäng and Löffler, 1992; ISO 11057) using flat circular coupons of filter media with a diameter of 15 cm. (Fig.1). The basic system (which is well known and needs no further description here) was modified by the additions of fast sensors to capture the exact position of the media surface, the pressure drop and certain visual information about the filter surface simultaneously with high temporal and spatial resolution. The one-dimensional movement of the filter in the direction of air flow was determined from the clean gas side by laser triangulation with a resolution of 0.1 µm; the time resolution for pressure signal and filter position measurement was 0.5 ms with a synchronization error on the order of 1 ms. A high-speed camera was used to observe cake detachment (Sobich et al., 2015).

Experiments were carried out with circular 150 mm coupons of a standard polyester needle felt. Samples were selected carefully to ensure comparable permeability. Key experimental variables included the thickness of the dust cake (equivalent to 1, 2 and 3 kPa) and the tank pressure (1, 4, 5 und 8 bar).

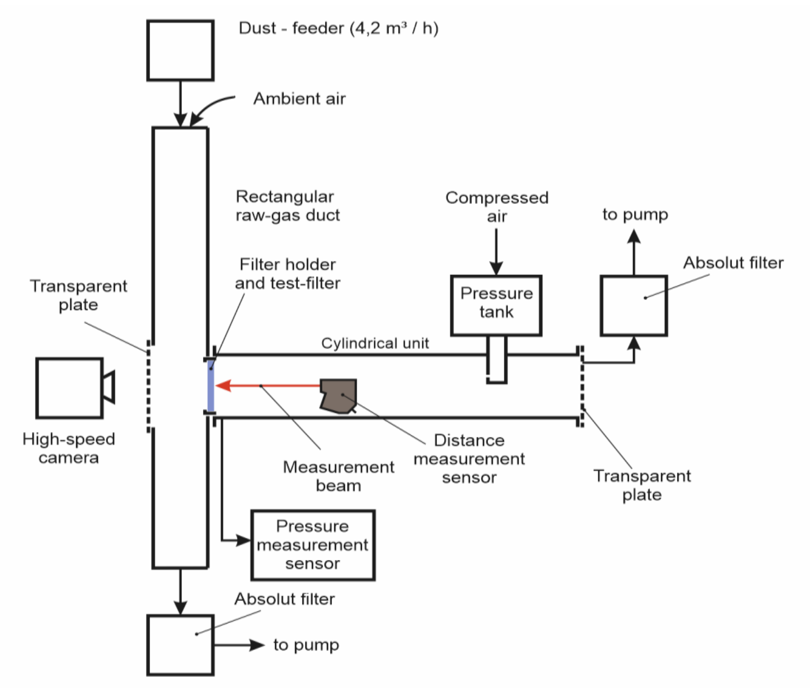

Figure 1: Schematic drawing of the modified laboratory scale test rig showing the positioning of the high-speed camera, the laser triangulation device, and the pressure sensors.

3. Results

The relationship between filter motion and pulse pressure is illustrated in Figure 2 with a typical data set obtained at 1 bar tank pressure. The right-hand side of the figure shows a composite diagram correlating the momentary filter position (measured at the center of the disc and expressed in mm relative to its position immediately before regeneration) with the momentary pulse pressure as obtained by the respective sensors. The left-hand side is a schematic to visualize the corresponding movement of the entire coupon. Characteristic phases of filter motion are indicated by numbers.

Position 1 represents the position of the filter at rest during the filtration phase, when the filter medium is fully extended toward the clean gas side (0 mm on the right-hand diagram). The media is stretched under pressure and therefore slightly larger than the filter mount. The operating pressure is negative at –1600 Pa. When the tank valve opens and the pressure on the clean gas site begins to build, the filter begins to release tensile stress and moves slowly forward to the raw gas site until being fully relaxed (Position 2).

As soon as the differential pressure across the filter becomes slightly positive, the filter abruptly snaps forward toward the raw gas side (the sector between position 2 and 3). The pressure remains quasi constant during this movement until the medium comes to a stop in its forward position. At that stage, the media is still relaxed mechanically (position 3). Only then does the pulse pressure continue to build and stretch the media until it reaches its fully extended forward endpoint (position 4).

When the valve closes, the pulse pressure quickly drops to a slightly negative value, at which the media relaxes, but does not yet move back because the differential pressure across the filter is not sufficient immediately after regeneration to push it back to the clean gas site (position 5). The filter snaps back when sufficient cake has been deposited (5 to 6) and then continues to stretch until max pressure drop is reached (6 to 1) and the cycle starts anew.

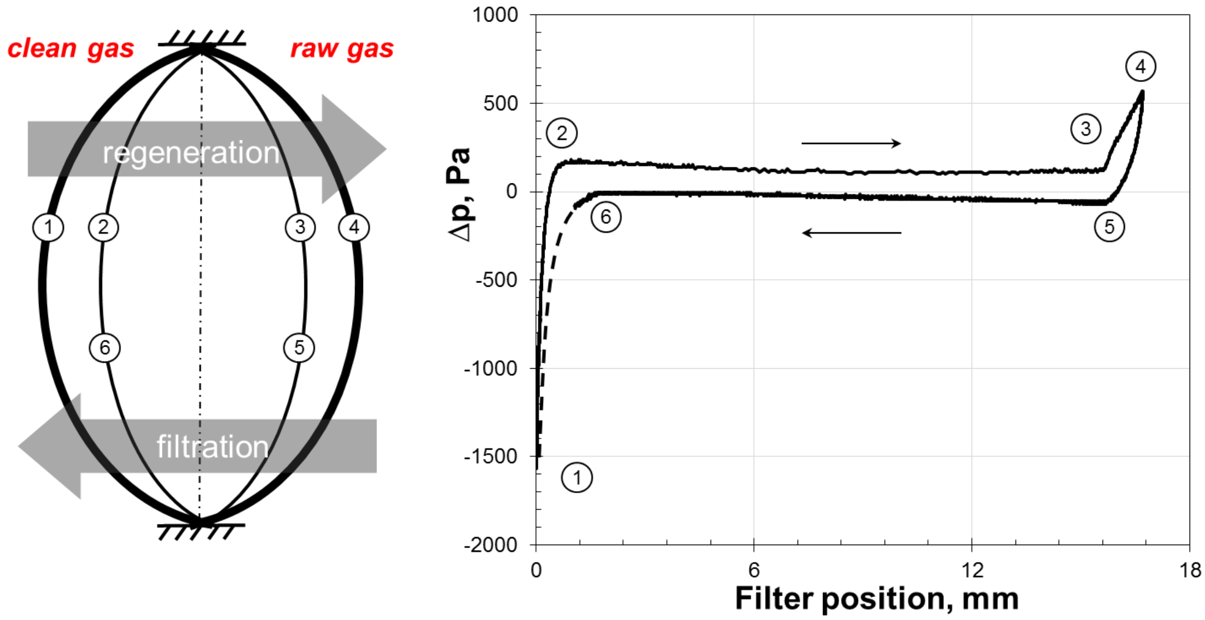

Figure 2: Stages of filter media movement related to the filter differential pressure.

Filter acceleration and cake detachment: One consequence of the filter movement are positive and negative acceleration forces that can be significant and have a direct impact on the cleaning process. Figures 3 and 4 illustrate the dynamics of this process for different tank pressures and also show the point in time of dust cake detachment as determined by high-speed camera.

According to Figure 3, cake detachment at 1 bar tank pressure is initiated much later 186 ms after triggering the cleaning pulse, compared to 35 ms at 5 bar, and 22 ms at 8 bar. The other important observation is the differential pressure at the moment of cake detachment, which is higher during regeneration at 1 bar (about 500 Pa) than at 5 bar (nearly zero). For 8 bar, the pressure is also very low but this is hard to see. The lack of correspondence between cake detachment and Δp, as well as the significant difference in time of detachment both suggest the existence of two different mechanisms of dust cake detachment depending on the value of tank pressure. In order to understand these mechanisms, the acceleration of media was calculated and compared.

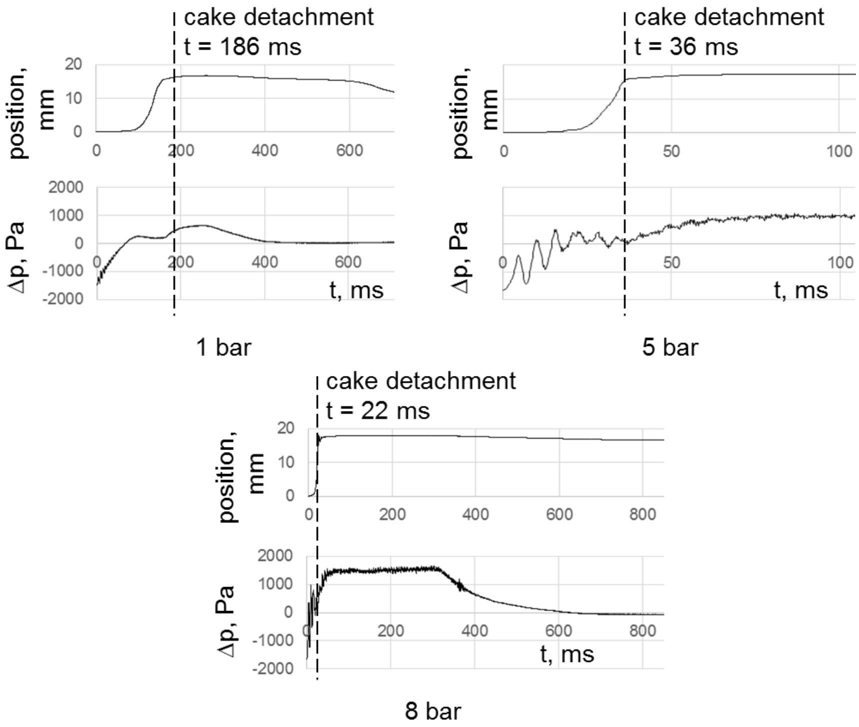

Figure 3: Filter movement and differential pressure during regeneration and moment of cake detachment for tank pressures of 1, 5 and 8 bar.

Figure 4 correlates the differential pressure, the filter position, the calculated acceleration, and the moment of cake detachment, again at a relatively low and a relatively high different tank pressure. At 4 bar the cake detachment begins at 52 ms, during a moment of insignificant Δp but significant deceleration of the filter media. At 1 bar, the situation is almost opposite with regard to the two parameters of influence at the moment of cake detachment: The deceleration of the filter media completely negligible, but Δp has moved into the positive region. The filter has reached its forward endpoint of movement and air is flowing through it. One could thus argue that in the first case we have detachment due to inertial forces (i.e. cake mass x deceleration) while in the second case by reversed flow.

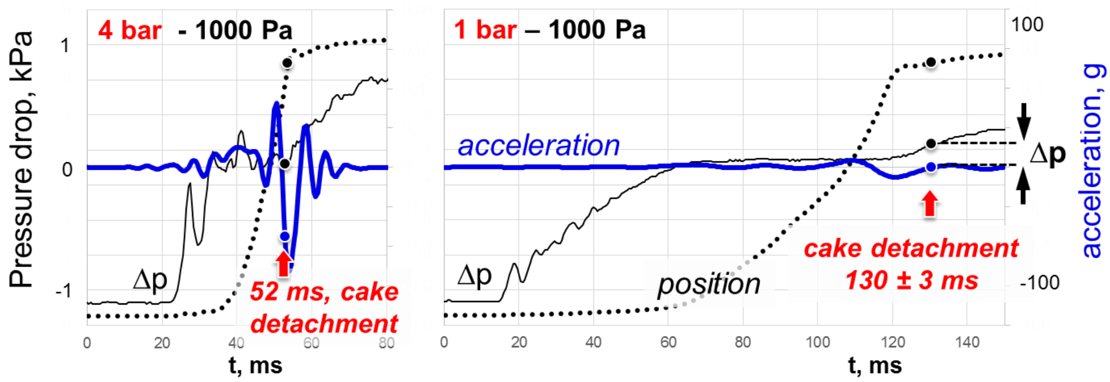

Figure 4: Filter position (dotted lines), filter acceleration (blue) and time of cake detachment (red) for tank pressures of 1 and 4 bar.

Figure 5 compares cake detachment at tank pressures of 4 and 5 bar, i.e. in the regime of inertial detachment. The cake mass is the same in both experiments (cake-Δp corresponding to 1000 mbar). We note that cake detachment is initiated at almost identical values of deceleration, at the moment when this negative acceleration is reached for the first time, and regardless of the maximal deceleration (which is higher for 5 bar than for 4 bar).

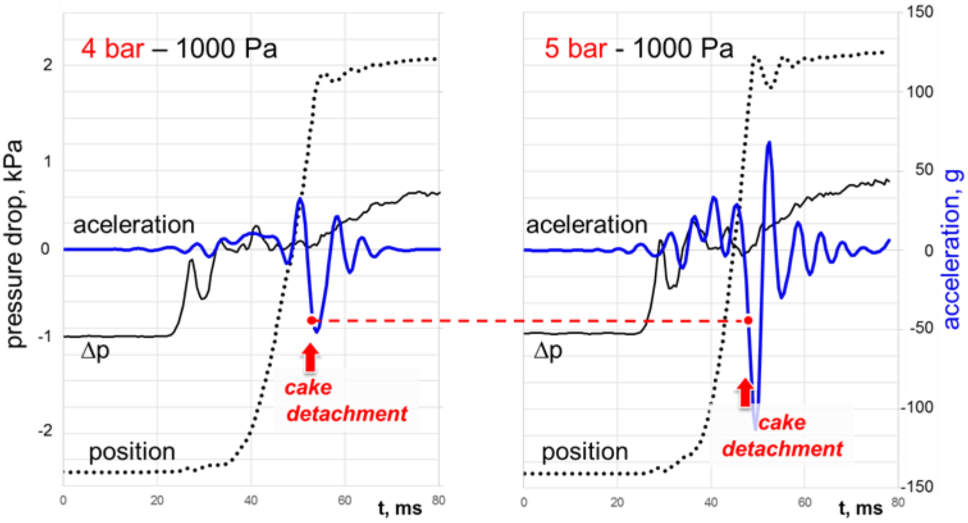

Figure 3: Deceleration of filter and cake detachment for regeneration with 4 bar (left) and 5 bar tank pressure (right).

In order to test our hypothesis, this experiment was extended to additional tank pressures and cake masses. The results are combined in Table 1. As we can see, the "detachment deceleration" stays constant for a given dust mass within the accuracy of our measurements, independent of the actual tank pressure. It decreases inversely proportional to the deposed cake mass on the filter surface. It therefore appears that the detachment force remains constant.

	4 bar	**5 bar**	**6 bar**
1000 Pa	48	44	46
2000 Pa	27	25	25
3000 Pa	16	15	16

Table 1: Deceleration of the filter at the moment of dust cake detachment for different tank pressures and dust cake masses.

***Optimization strategies for the regeneration process**:* Most of the differential pressure drop during filter operation is due to the dust cake. For a successful regeneration it is therefore mandatory to achieve a through detachment of the cake (Dittler et al., 1999), either by a high pulse intensity (i.e. sufficient deceleration of filter media) or, presumably, by sufficient backpressure in case of regeneration with a rather low pulse intensity. The second important consequence of regeneration is the reduction of the residual pressure drop, which presumably also has a major effect on the emission level. It well known, that emission occurs immediately after regeneration. The emissions level depends of residual pressure drop – the cleaner the filter, the higher the emission (Kurtz et al. 2016).

Based on studies conducted it can be argued that independent from regeneration “intensity” (tank pressure in this case) the dust cake detachment takes a place at the beginning of the regeneration impulse (Fig. 6). The rest of impulse is taken to the backwashing of filter media - displacement of the dust from the medium inside, which have to determine the residual drop of filter after regeneration. Thus, it seems to be possible to optimise regeneration process by reducing of back pulse length so as to remove the dust cake only, without medium inside cleaning. However such experiment requires a modification of an existing labour filter rig, to provide ultra-short jet pulse regeneration.

4. Summary and Conclusions

The movement of filter media during regeneration was studied as a function of the intensity of the pressure pulse. The filter movement was also correlated with the moment of cake detachment. For this purpose, experiments were carried out on filter coupons at different tank pressures and cake masses.

It was confirmed that cake detachment can occur either due to inertial of pressure forces. In case of a sufficient tank pressure, the inertial force dominates and initiates cake detachment early on during the pulse sequence – typically during the first 10 to 40 ms. Otherwise, if the generated negative acceleration is insufficient, cake detachment occurs much later (130 to 190 ms) presumably due to flow reversal. It was further shown quantitatively for a given combination of filter medium and dust type, that inertial detachment occurs always at the same detachment force.

5. Acknowledgements

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6. Literature

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